

ANNUAL REPORT\*

(December 1, 1963 to November 30, 1964)

GRANT NsG 56-60

From

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

To

THE CALIFORNIA INSTITUTE OF TECHNOLOGY

By

Harrison Brown, Principal Investigator

Bruce C. Murray, Associate Principal Investigator

July 1, 1965

Pasadena, California

\*Also includes Semi-Annual Status Report through June 30, 1965

## CONTENTS

	<u>Page</u>
1. INTRODUCTION .....	1
2. SUMMARY OF RESEARCH .....	2
3. GRADUATE STUDENT PROGRAM.....	5
4. RELATIONSHIP TO SPACE PROGRAM .....	7
5. FINANCIAL SUMMARY. ....	8

## 1. INTRODUCTION

This is a report of research activities carried out during the fifth year of grant NsG 56-60, which ended November 30, 1964, from the National Aeronautics and Space Administration to the California Institute of Technology. Also included is a summary report of our work during the first six months of the present grant year, i.e., through June 30, 1965.

Our research is summarized in Section 2 along with a listing of publications. The graduate student program is outlined in Section 3. Relationship to the Space Program is discussed in Section 4 and a financial summary is presented in Section 5.

The permanent research staff remained more or less unchanged during the fifth grant year with the exception of the replacement of James Kroth as Research Assistant by Richard Davis. During the first half of the present grant year a temporary employee, Barbara Schwartz, left to return to graduate work, and a second part-time employee, Carolyn Prunty, has been added to the staff. A full-time computer aid and numerical analyst, Tauba Anderson, also joined our staff during the first half of the present grant year. Dr. Robert Wildey has left to join the staff of the U. S. Geological Survey in Flagstaff. His termination was effective the last of June.

## 2. SUMMARY OF RESEARCH

Our research continues to be directed in three principle areas:

1) Characteristics of planets, meteorites and asteroids, particularly regarding orbital distribution, which may be clues as to the origin and evolution of those objects as well as to the Solar System as a whole.

2) Ground-based physical observations of the Moon and Planets, and related interpretations, in the visible and long-wavelength infrared.

3) Laboratory investigations of the thermal radiative properties of powders in vacuum, with applications to the interpretation of lunar infrared observations.

The compositions of meteorites described in the last Annual Report have been implemented during the grant year by additional analyses, bringing to 72 the total number of stony meteorites analyzed. All of these analyses have been assembled for incorporation into a complete program report which will be prepared soon for separate distribution.

A limited comparison of a portion of these tabulations with data obtained in other laboratories where different analytical methods were used was made with gratifying results.

The second of this continuing series of investigations is directed at the analysis of separated non-metallic and metallic portions of chondrites. It is hoped that it will be possible to correlate more directly different meteoritic substances with one another, with terrestrial differentiation products as represented by basaltic and granitic rocks, and with materials on the surface of the Moon.

Some support was directed to the electron probe analyses of nickel in iron meteorites. Good working relations have continued with institutions possessing large meteorite collections, notably Arizona State University, the American Museum of Natural History, and the Smithsonian Institution.

An attempt to estimate the abundance of planetary systems by making use of the luminosity function for stars and taking into account the likely chemical composition of planets in relation to the composition of main-sequence stars. It was concluded that

planetary systems might be extremely abundant. The possible distribution of planets around stars has been studied and it is concluded that favorable conditions for life processes may be far more abundant than has generally been thought possible.

The orbital elements of more than 1650 asteroids have been brought up to date and placed on punch cards. The Stromberg Carlson plotter, which was made available to us, has been used to sort through the data for regularities. This has been done with the raw orbital data, as well as for the data corrected for secular perturbations. The well-known Hirayama families as well as some less well-defined families have been confirmed. Additional groups appear also.

These correlations and plots will be made available to interested persons later in the year. The correlations will be published.

We are indebted to Dr. Julius Kane who has collaborated with us in the establishment of the computer-plotter program.

The 24-inch telescope at White Mountain permitted us to acquire good observations of thermal emission of the Moon during the lunar nighttime, most of which have been reduced but are not yet in published form. A surprising discovery was the fact that some of the Mare regions remain warm compared to the upland regions. The explanation for this phenomenon is not known. The 200-inch telescope was used effectively to yield the highest resolution and most sensitive observations to date on Jupiter and Venus. These results are currently in press. Among the new discoveries in this program was the fact that the anti-solar point on the planet Venus emits more thermal radiation than the solar point, contrary to one's common sense expectation. The shadow phenomenon on Jupiter has not been observed again inspite of repeated attempts. The original observation, however, was a clear-cut one and the conclusion therefore is that the phenomenon is of a variable nature.

The thermal radiation from the asteroid Vesta was observed using the 200-inch telescope for the first time. The infrared photometric data obtained of the Galilean satellites, as

well as of Vesta and Ceres, by Dr. Frank Low are being analyzed thoroughly and the results will be published during the next grant year. Combined infrared and visible photometry of these objects will prove to be an extremely important tool in analysis of their surface conditions.

Laboratory studies of silicate powders and assimilated lunar conditions are discussed in Section 3.

### 3. GRADUATE STUDENT PROGRAM

Our graduate student program continues to gain momentum both in numbers and in the diversity of student research. During the winter of 1964 and the spring of 1965 two first year graduate students, Thomas McCord and Dennis Matson, began a series of careful observations of the lunar luminescence phenomenon using the 60-inch Snow telescope on Mt. Wilson. The Line Depth Method, using both photoelectric and photographic techniques, was selected.

Observations of the H and K  $\text{Ca}^{II}$  lines of five selenographic positions in Mare Serenitatis were made on three different nights using a 1P21 photo-detector and the Cassegrain scanner on the 60-inch telescope at Mt. Wilson. An analysis of these data yielded a detection level of 0.5 percent luminescence with a high probability of the detection of 3% luminescence at Le Monnier during one of the three nights. During the analysis several improvements were suggested which should lead to a detection level below 0.1% luminescence. More photoelectric observations utilizing these improvements are planned for the near future.

A number of photographic spectra were made of selected lunar localities on each of several full moon nights utilizing the Snow telescope. Unfortunately the signal to noise ratio in the bottom of the H and K Fraunhofer lines was extremely low and no conclusions could be drawn from the data. However, it is felt that by use of a special emulsion and techniques for sensitizing the plates, the signal to noise can be increased enough to carry out the luminescence observations. These programs are continuing into the next grant year.

Alexander Goetz is continuing his Ph.D. studies on infrared emissions from silicate powders under simulated lunar conditions. A lightweight (25 lbs) 8-14 micron IR spectrometer and etector dewar have been built, tested and found to operate within design specifications. A vacuum container with a liquid  $\text{N}_2$  shroud and cold chopper, driven from

outside, has been completed to facilitate the measurement of the emission of powders in a vacuum under strong thermal gradient conditions. Preliminary measurements have yielded IR spectra of quartz with a surface temperature of  $220^{\circ}\text{K}$  at 0.06 micron resolution with a peak signal to noise ratio of 150:1. It is expected that he will be able to finish his laboratory work and proceed to the telescope with his equipment during the current grant year.

Mr. David Roddy continues his Ph.D. thesis investigation of the origin of the Flynn Creek crypto-volcanic structure. It is expected that he will complete his studies during the summer. Grant NsG 56-60 supports only certain laboratory phases of that investigation.

Mr. Hugh Kieffer is in the process of selecting his Ph.D. thesis topic, which will be in the field of planetary science.

Three new graduate students in planetary science are expected to enroll in the fall, two of whom will have had one year of graduate work at other institutions. In addition, two graduate students in geophysics have undertaken research in planetary science and will probably use the work for their oral proposition examinations.



#### 4. RELATIONSHIP TO SPACE PROGRAM

As has been our policy in the previous grant years, we participate in the space program in two ways: (1) direct participation in the planning and evaluation of scientific experiments in the unmanned program, and (2) background research aimed at increasing the effectiveness of future space activities. In the former category, Dr. Murray continues to collaborate with Dr. Leighton on the Mariner IV TV experiment, which has taken considerable time during the last six months. A rather large program including background research has been set up jointly with the Jet Propulsion Laboratory and is deemed essential to the preparation and interpretation of Mariner photographs as well as in the design of any future photographic systems for the planet Mars. The "Martian Horror Story" is one product of this research. Only small direct costs pertinent to the Mariner program have been charged to the present grant in spite of the large effort under way.

Dr. Brown's continuing program of background studies of the analytical value of X-ray fluorescence for remote investigation of the Moon and planets, in collaboration with Dr. Albert Metzger of the Jet Propulsion Laboratory, has continued at about the same level as during the latter part of the previous grant year.

PUBLICATIONS UNDER NASA GRANT N5G 56-60

FOR GRANT YEARS JAN. 1, '60 TO NOV. 30, '63

- Brown, H., "The Density and Mass Distribution of Meteoritic Bodies in the Neighborhood of the Earth's Orbit", J.G.R., Vol. 65, No. 6, pp. 1679-1673, 1960.
- Brown, H., "Addendum: The Density and Mass Distribution of Meteoritic Bodies in the Neighborhood of the Earth's Orbit", J. G. R., Vol. 66, No. 4, pp. 1316-1317, 1961.
- Brown, H., and Irene Goddard, "A Study of Some Non-Random Aspects of the Frequency of Meteorite Falls", Isotopic and Cosmic Chemistry, North-Holland Publishing Co., pp. 365-384, 1963.
- Duke, M., D. Maynes, and H. Brown, "The Petrography and Chemical Composition of the Bruderheim Meteorite", J.G.R., Vol. 66, No. 10, pp. 3557-3563, 1961.
- Millard, H. T., Jr., and H. Brown, "Meteoritic Time-of-Fall Patterns", Icarus, Vol. 2, No. 2, pp. 137-151, 1963.
- Moore, C. B., and H. Brown, "Barium in Stony Meteorites", J.G.R., Vol. 68, No. 14, pp. 4293-4296, 1963.
- Murray, B. C., "The Artificial Earth Satellite - A New Geodetic Tool", American Rocket Society Journal, pp. 924-931, 1961.
- Murray, B. C., and A. B. Lees, "An 'Invariant' Property of Satellite Motion in a Dissipative Medium", Advances in the Astronautical Sciences, Vol. 8, pp. 294-302, 1962.
- Murray, B. C., and R. L. Wildey, "Observations of Jupiter and the Galilean Satellites at 10 Microns", Ap. J., Vol. 139, No. 3, pp. 986-993, 1964.
- Murray, B. C., and R. L. Wildey, "Stellar and Planetary Observations at 10 Microns", Ap.J., Vol. 137, No. 2, pp. 692-693, 1963.
- Murray, B. C., and R. L. Wildey, "Surface Temperature Variations During the Lunar Nighttime", Ap.J., Vol. 139, No. 2, pp. 734-750, 1964.
- Murray, B. C., R. L. Wildey, and J. A. Westphal, "Infrared Photometric Mapping of Venus Through the 8-14 Micron Atmospheric Window", J.G.R., Vol. 68, No. 16, pp. 4813-4818, 1963.
- Murray, B. C., R. L. Wildey, and J. A. Westphal, "Venus: A Map of Its Brightness Temperature", Science, Vol. 140, No. 3565, pp. 391-392, 1963.
- Nichiporuk, W., and H. Brown, "Platinum and Iridium Abundances in Meteorites", Phys. Rev. Letters, Vol. 9, No. 6, pp. 245-246, 1962.
- Pogo, Alexander, "Annotated Bibliography of Physical Observations of the Moon", Division of Geological Sciences, California Institute of Technology, 1961.
- Pohn, H., "New Measurements of Steep Lunar Slopes", P.A.S.P., Vol. 75, No. 443, pp. 186-187, 1963.

- Pohn, H., B. C. Murray, and H. Brown, "New Applications of Lunar Shadow Studies", P.A.S.P., Vol. 74, No. 437, pp. 93-105, 1962.
- Roddy, D. J., J. B. Rittenhouse, and R. F. Scott, "Dynamic Penetration Studies In Crushed Rock Under Atmospheric and Vacuum Conditions", A.I.A.A. Journal, Vol. 1, No. 4, pp. 868-873, 1963.
- Watson, K., and C. A. Bauman, "Apparatus to Measure the Thermal Conductivity of Powders in Vacuum From 120-350°K, Rev. Sci. Instr., Vol. 34, No. 11, pp. 1235-1238, 1963.
- Watson, K., B. C. Murray, and H. Brown, "Possible Presence of Ice on the Moon", J.G.R., Vol. 66, No. 5, pp. 1598-1600, 1961.
- Watson, K., B. C. Murray, and H. Brown, "The Behavior of Volatiles on the Lunar Surface," J.G.R., Vol. 66, No. 9, pp. 3033-3045, 1961.
- Watson, K., B. C. Murray, and H. Brown, "The Stability of Volatiles in the Solar System", Icarus, Vol. 1, No. 4, pp. 317-327, 1963.
- Westphal, J. A., "New Observations of Atmospheric Emission and Absorption in the 8-14 Micron Region", Colloque International d'Astrophysique tenu a l'Universite de Liege, Memoires Soc. R. Sc. Liege, cinquieme serie, tome IX, pp. 360-361, 1964.
- Westphal, J. A., B. C. Murray, and D. E. Martz, "An 8-14 Micron Infrared Astronomical Photometer", Applied Optics, Vol. 2, pp. 749-753, 1963.
- Willey, R. L., and B. C. Murray, "10 Micron Photometry of 25 Stars From B8 to M7", Ap.J., Vol. 139, No. 2, pp. 435-441, 1964.
- Willey, R. L., and B. C. Murray, "Ten Micron Stellar Photometry - First Results and Future Prospects", Colloque International d'Astrophysique tenu a l'Universite de Liege, Memoires Soc. R. Sc. Liege, cinquieme serie, tome IX, pp. 460-468, 1964.

PUBLICATIONS UNDER NASA GRANT NsG 56-60  
FOR GRANT YEAR DEC. 1, '63 TO NOV. 30, '64

- Brown, H., "Planetary Systems Associated with Main Sequence Stars", Science, Vol. 145, No. 3637, pp. 1177-1181, 1964.
- Willey, R. L., "A Computer Program for the Transformation of Lunar Observations from Celestial to Selenographic Coordinates", Icarus, Vol. 3, No. 2, pp. 136-150, 1964.
- Willey, R. L., "Hot Shadows of Jupiter", Science, Vol. 147, No. 3661, pp. 1035-1036, 1965.
- Willey, R. L., "Lunar Luminescence", P.A.S.P., Vol. 76, No. 449, pp. 112-114, 1964.
- Willey, R. L., "On Line-Blanketing Normalization of Subdwarf Photometry", Ap.J., Vol. 141, No. 3, pp. 943-948, 1965.
- Willey, R. L., "On the Infrared Opacity of Jupiter's Outer Atmosphere", Icarus, Vol. 3, No. 4, pp. 332-335, 1964.
- Willey, R. L., "Photometry of the Earth from Mariner II", J.G.R., Vol. 69, No. 21, pp. 4661-4672, 1964.
- Willey, R. L., "The Stellar Content of  $\eta$  and  $\chi$  Persei - Cluster and Association", Ap. J. Supplement Series, Vol. VIII, No. 84, pp. 439-496, 1964.
- Willey, R. L., "The Moon's Photometric Function", Nature, Vol. 200, p. 1056, 1964.
- Willey, R. L., and H. A. Pohn, "Detailed Photoelectric Photometry of the Moon", A.J. Vol. 69, No. 8, pp. 619-634, 1964.

PUBLICATIONS UNDER NASA GRANT NsG 56-60  
FOR GRANT YEAR DEC. 1, '64 TO JUNE 30, '65

- Murray, B. C., "A Martian Horror Story - Requirements vs Capabilities for the Photographic Exploration of Mars", submitted to Adv. in Astr. Sci., Vol. 17, in press, 1965.
- Murray, B. C., J. A. Westphal, and R. L. Wildey, "The Eclipse Cooling of Ganymede", submitted as a Letter to the Editor, Ap.J., in press, 1965.
- Nichiporuk, W. and H. Brown, "The Distribution of Platinum and Palladium Metals in Iron Meteorites and in the Metal Phase of Ordinary Chondrites", J.G.R., Vol. 70, No. 2, pp. 459-470, 1965.
- Short, J. M.\* and C. A. Andersen\*\*, "Electronprobe Analyses of Nickel Diffusion Gradients in Iron Meteorites and the Cooling History of the Meteorite Parent-Bodies", J.G.R., in press, 1965.
- Westphal, J. A., R. L. Wildey, and B. C. Murray, "The 8-14 Micron Appearance of Venus Before the 1964 Conjunction", submitted as a Note to Ap.J., in press, 1965.
- Wildey, R. L., "On the Interpretation of Thermal Emission Maps of Jupiter", submitted as a Letter to J.G.R. in press, 1965.
- Wildey, R. L., B. C. Murray, and J. A. Westphal, "Thermal Infrared Emission of the Jovian Disk", submitted to J.G.R., in press, 1965.

---

\*Present Address: Space Sciences Division, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California

\*\*Hasler Research Center, Applied Research Laboratories, Goleta, California